

Hypothesis 3: Physical processes, (e.g. resuspension, turbulence) associated with the plume event are important in determining the nutrient and light climate, and in structuring the biological communities throughout the spring isothermal period, and in setting the conditions for the critical 'spring bloom' period.

What have we learned so far? (as of 11/99)

- Primary production is reduced within the plume - low light.
- Heterotrophic production is high in the plume - sediment supplied substrate.
- Events don't seem critical in supplying "seed" populations of diatoms.
- Although substantial P is resuspended, plume algae are P starved.

Results

- Event and monthly surveys of nutrients and PSS.
- Detailed optical characterization of plume and adjacent waters.
- Species specific primary production measurements.
- Microzooplankton-distinct communities in plume region- important grazers of small PP.
- Feeding studies of calanoids on PP & MZP.
- Size shift and change in ZP composition between 1998 and 1999 -> smaller & cyclopoids replaced calanoids.

Future Plans

- More spatial coverage.
- Extend process cruises into spring bloom.
- Expand ZP feeding studies.
- Enhance integration of field experiments & modeling.

Reports (9/00)

The Impact of a Recurrent Coastal Plume on Phosphorus Dynamics and Production in Lake Michigan -- Thomas H. Johengen, and James B. Cotner

Processing of nitrogen by autotrophic and heterotrophic organisms in southern Lake Michigan -- Wayne S. Gardner and Mark McCarthy, Joann Cavaletto, Peter Lavrentyev.

The impact of a recurrent coastal plume on phosphorus dynamics and production in Lake Michigan -- J. Cotner, Biddanda, and T. Johengen.

The Microbial Food Web composition and dynamics during the winter-spring Transition in southern Lake Michigan -- Peter Lavrentyev, Paul Kovalcik, Deborah Hersha, and Wayne S. Gardner (In collaboration with: Henry Vanderploeg, Joann Cavaletto, and Marie Bundy.

Impact of Episodic Transport and Resuspension on Coastal Phytoplankton Processes: A Case Study of the Lake Michigan Recurrent Coastal Plume (RCP) -- G. L. Fahnenstiel, S. E. Lohrenz, D. F. Millie, and O. M. E. Schofield.

Effects of resuspension events on restructuring phytoplankton communities -- Linda M. Goad, and Matthew L. Julius.

Daphnia resting egg production and resuspension: records from sequential sediment traps -- W. Charles Kerfoot, Xiao Ma, Brian J. Eadie, and J. Budd.

The Recurrent Coastal Plume in Lake Michigan: A Critical Event for Copepod Reproduction and Recruitment -- H. Vanderploeg and M. Bundy.

Modeling Studies of the Plume Ecosystem in Lake Michigan -- Changsheng Chen, Lixia Wang, Rubao Ji, David J. Schwab, Dmitry Beletsky, J. W. Budd, Gary L. Fahnenstiel, T. H. Johengen, H. Vanderploeg, Brian Eadie, Wayne Gardner, Peter Lavrenyev, and Marie Bundy.

**Cooperative Institute for Limnology and Ecosystems Research
Project Report**

Name: Thomas H. Johengen, CILER, University of Michigan
James B. Cotner, University of Minnesota

Project: C/III-35: The Impact of a Recurrent Coastal Plume on Phosphorus Dynamics and Production in Lake Michigan

Period of Activity: 09/01/97 – 06/30/01

Report Type: Progress Update Report

Overview of Research Activities and Results:

This research project represents one of twelve separately funded components of the parent proposal entitled; *The Impact of Episodic Events on the Nearshore-Offshore Transport of Biogeochemically Important Materials in the Great Lakes (EEGLE)*. Our project is designed to examine the influence of major episodic events on phosphorus (P) availability and dynamics in the southern basin of Lake Michigan. Efforts will focus on a recurrent coastal plume that develops in the spring. Understanding the impact of episodic events on P availability has important implications for ecosystem structure and function because primary productivity in this system is P-limited.

The goal of this project is to determine the importance of the recurrent coastal plume to transport, composition and biological availability of P. To achieve this goal, we will fulfill the following objectives: (1) To determine the potential sources, distributions and fluxes of P in the recurrent coastal plume and (2) To determine the impact of P associated with the recurrent coastal plume on phytoplankton and bacterioplankton production in Lake Michigan. Specifically, we will examine the impact of these suspended particles on microbial (heterotrophic bacteria and phytoplankton) community productivity and nutrient limitation through a combination of bioassays (growth rate measurements, alkaline phosphatase activity), nutrient chemistry and stoichiometry, and P regeneration rates.

Year one of the study (7/97 – 6/98) was defined as a pilot year and was designed to allow for the development of field sampling strategies, experimental designs, and new instrumentation. These tasks were accomplished in conjunction with all the investigators from the other projects through a series of workshops and research cruises. We participated in five major research cruises on Lake Michigan between January and May of 1998. All samples have been processed and analyzed from year 1 field surveys and experiments and were submitted to the project's database. As part of this project, a new nutrient analyzer was purchased and brought on line. A post-doc was hired through the University of Minnesota and began working in June 1998.

A late summer cruise was conducted in the start of year 2 (7/98 – 6/99) to measure bacterial production, nutrient concentrations, phosphorus cycling, and indicators of P-deficiency at our established transect sites throughout the southern basin. We are attempting to establish whether the effects of the plume can be observed in phosphorus dynamics and heterotrophic production throughout the summer and periods of maximum production. Five research cruises were conducted from January – June of 1999 to survey the lake during pre-, plume-, and post-plume conditions. All samples have been processed and analyzed from year 2 field surveys and experiments and were submitted to the project's database.

Year three activities (7/99 – 6/00) built upon results and strategies developed during 1999. Year three was the last full-scale field year, and cruises were again conducted to survey the lake before, during, and after the resuspension plume event. During the cruises we conducted surveys of nutrient concentrations, nutrient limitation, bacterial abundance, and total suspended material. At selected sites we performed experiments on bacterial production, nutrient uptake kinetics and equilibrium reactions. Nine cruises were carried out during this field year. In addition to the cruises, a multi-investigator (cross-project) experiment was conducted using mesocosms to examine the individual and synergistic effects of riverine inputs and sediment resuspension on nutrient dynamics, bacterial production, and phytoplankton production.

All hands planning meeting were conducted in October 1998 and October 1999 to coordinate sampling and research activities and to present results to a review panel of the NOAA/COP and NSF/CoOP funding agencies. We have made multiple presentations of our results at professional scientific meetings, at project workshops, and at student research symposiums. In addition we have published several manuscripts, and have a significant number in review or in preparation.

Publications:

- Cotner, J.B., and B.A. Biddanda. 2000. Small players, large role: Microbial influence on auto- heterotrophic coupling and biogeochemical processes in aquatic ecosystems. Submitted to *Ecosystems*.
- Biddanda, B., M. Ogdahl and J.B. Cotner. 2000. Contribution of heterotrophic bacteria to planktonic biomass and respiration in lakes and the ocean. *Limnology and Oceanography*. In press.
- Cotner, J.B., T.H. Johengen, and B.A. Biddanda. 2000. Intense winter heterotrophic production stimulated by benthic resuspension. *Limnology and Oceanography*. In press.
- Cotner, J.B. 2000. Heterotrophic bacterial growth and nutrient limitation in large, oligotrophic lakes and oceans. *Verh. Internat. Verein. Limnol.* In press.
- Eadie, B., D. Schwab, T. Johengen, P. Lavrentyev, G. Miller, R. Holland, G. Leshkevich, M. Lansing, N. Morehead, J. Robbins, N. Hawley, D. Edgington, and P. Van Hoof (*In Review*). Characterizing a major episodic event: a recurrent winter-spring plume in southern Lake Michigan. *J. Great Lakes Res.*

In preparation:

- Chen, C., R. Ji, D.J. Schwab, D. Beletsky, G.L. Fahnenstiel, T.H. Johengen, H. Vanderploeg, B. Eadie, M. Bundy, W. Gardner, and J.B. Cotner. A coupled biological and physical model of Lake Michigan: 1-D experiments.
- Cotner, J.B., M.L. Ogdahl, and B.A. Biddanda. A rapid, fluorometric method for determining bacterial biomass and growth rates in aquatic systems. Will be submitted to *Aquatic Microbial Ecology*, Fall 2000.
- Biddanda, B.A., and J.B. Cotner. Effect of sunlight on the bioavailability of limnetic dissolved organic matter. Will be submitted to *Journal of Great Lakes Research*.
- Biddanda, B.A., and J.B. Cotner. Planktonic respiration and carbon flux through bacterioplankton in southern Lake Michigan. Will be submitted to *Limnology and Oceanography*.
- Cotner, J.B. and B.A. Biddanda. Microbial P demand and cycling in southern Lake Michigan. Will be submitted to *Journal of Great Lakes Research*.

Presentations:

- Ibrahim, A. and T. Johengen. Episodic Events Great Lakes Experiment: The recurrent coastal plume and its impact on distributions of phytoplankton in Lake Michigan. Poster presentation at Summer Research Opportunity Program Symposium, University of Michigan. August 2000, Ann Arbor, MI.
- Biddanda, B., and J. Cotner. Contribution of bacteria to planktonic biomass and respiration in lakes and ocean. ASLO annual meeting, 5-9 June, 2000, Copenhagen, Denmark. (Invited).
- Cotner, J., B. Biddanda, and T. Johengen. Importance of terrestrial and other non-algal carbon sources to bacteria in large lakes. ASLO annual meeting, 5-9 June, 2000, Copenhagen, Denmark. (Invited).
- Cotner, J.B., and B.A. Biddanda. Microbes, trophic state and biogeochemical processes. University of Minnesota LiMNology Workshop, 19-20 February 2000, Siren, WI.
- Biddanda, B.A., and J.B. Cotner. DOM & sun: Effect of sunlight on the bioavailability of limnetic and marine dissolved organic matter. University of Minnesota LiMNology Workshop, 19-20 February 2000, Siren, WI.
- Ogdahl, M.L., B.A. Biddanda, and J.B. Cotner. PicoGreen fluorometry for determination of aquatic bacterial abundance and growth. Poster at University of Minnesota LiMNology Workshop, 19-20 February 2000, Siren, WI.
- Blood, S., B.A. Biddanda, and J.B. Cotner. Phosphorus availability to Lake Michigan plankton. Poster at University of Minnesota LiMNology Workshop, 19-20 February 2000, Siren, WI.
- Cotner, J.B., B.A. Biddanda, and T.H. Johengen. Bacterial production and nutrient dynamics in the Lake Michigan resuspension plume. EEGLE Workshop, 28-30 October 1999, Minneapolis, MN.
- Biddanda, B.A., and J.B. Cotner. Plankton respiration and carbon flux through bacterioplankton in southern Lake Michigan. EEGLE Workshop, 28-30 October 1999, Minneapolis, MN.
- Johengen, T.H. Changes in nearshore-offshore distributions of particulate matter and nutrients in Lake Michigan in response to a recurrent coastal sediment plume. EEGLE Workshop, Oct. 1999, Minneapolis, MN.
- Johengen, T.H., Vanderploeg, H.A., Ruberg, S.A., and Lang, G.A. Chemical and Biological Distributions Associated with the Recurrent Coastal Sediment Plume in Southern Lake Michigan. International Association of Great Lakes Research Conference, June 1999, Cleveland, OH.
- Mendelowitz, J. and T. Johengen. The effects of a recurrent coastal plume on phosphorus cycling in Lake Michigan. Poster presentation at Undergraduate Research Opportunity Program Symposium, University of Michigan. August 2000, Ann Arbor, MI.
- Biddanda, B. A., M. L. Ogdahl, and J. B. Cotner. Carbon flux through bacterioplankton in lakes and the ocean: Regulation by system productivity. ASLO Aquatic Sciences Meeting, 1-4 February 1999, Santa Fe, NM.

Cotner, J.B., and B.A. Biddanda. 1999. Microbial mediation of C and P dynamics in large lakes and oceans. Large Lakes Observatory, October 1999. Invited.

Cotner, J.B. 1999. Bacteria as a constraint on productivity in lakes and oceans. Cedar Creek Summer Seminar, July 1999.

Cotner, J.B., T.H. Johengen, and B.A. Biddanda. Rapid bacterial production in extremely cold waters is stimulated by benthic-pelagic exchanges. ASLO Aquatic Sciences Meeting, 1-4 February 1999, Santa Fe, NM.

Cotner, J.B. 1998. Heterotrophic bacterial growth and nutrient limitation in large, oligotrophic lakes and oceans. SIL Congress, 9-14 August 1998, Dublin, Ireland.

Cotner, J.B., T.H. Johengen, and B.A. Biddanda. Microbial cycling of nutrients in the coastal plume. EEGLE Workshop 14-16 October 1998, Ann Arbor, MI.

Cotner, J.B. 1998. Alterations to biogeochemical processes in lakes and oceans: Important human influences. Seminar at University of Minnesota Geography Department, October 1998.

Biddanda, B.A. 1998. Variable carbon flux through bacterioplankton: biogeochemical implications. Seminar at University of Minnesota, Dept. Ecology, Evolution, and Behavior, September 1998.

Cotner, J.B. 1998. Heterotrophic Bacterial Growth in Aquatic Ecosystems. Seminar at University of Minnesota-Duluth, Biology Dept. April, 1998. (Invited).

Interactions

There are approximately 40 principal investigators from 30 different universities, institutions, and governmental agencies collaborating on this project. Principal investigators interact through a series of annual workshops and collaborative research cruises. Workshops are held to coordinate research objectives, plan field activities, and share results. Daily interactions and information exchange are conducted through the project's web site and group mailing lists.

T. Johengen has served as the project coordinator for developing the field sampling program for the biological/chemical survey cruises and has served as the chief scientist for most of these cruises.

EEGLE-KITES collaborative cruise, June 2000. We worked with Sarah Green of Michigan Tech to examine *in situ* photo-oxidative versus biological degradation of organic matter in Lake Superior. Work related to this project was recently written about in the Minneapolis Star Tribune. The article can be read online at:

<http://www.startribune.com/stOnLine/cgi-bin/article?thisSlug=BLUE29&date=29-Aug-2000&word=cotner>.

Other Funding/Support: This project is financially supported by the NSF CoOp and the NOAA COP programs. In addition, the U.S. EPA has contributed greatly to the project in terms of research vessel support and the funding of collaborative research projects that enhanced the scope of the EEGLE project.

Degrees Earned: Simba Blood, B.S. Department of Ecology, Evolution, and Behavior, University of Minnesota.

Processing of nitrogen by autotrophic and heterotrophic organisms in southern Lake Michigan.

Wayne S. Gardner and Mark McCarthy, The University of Texas; Joann Cavaletto, NOAA-GLERL; Peter Lavrentyev, University of Akron.

Objectives:

1. Evaluate nitrogen dynamics in southern Lake Michigan relative to plume and microbial food web characteristics.
2. Determine whether phosphorus limits the microbial turnover of nitrogen compounds.

Approach:

- A series of 24-h incubation bottle experiments were conducted at selected stations in southern Lake Michigan in March and June 1999 and March and May 2000 to examine potential nitrogen uptake and regeneration rates by microbial food web organisms.
- N-15 labeled ammonium and amino acids were added to Lake Michigan water, in the presence and absence of added phosphorus, and net fluxes of the added nitrogen compounds were observed in light and dark bottles over 24 h.
- Samples were collected at the same stations for enumeration of microbial food web organisms to compare with N fluxes.

Results:

- Net uptake or regeneration rates for ammonium and amino acids were measurable over 24 h at most stations.
- Fluxes of ammonium ranged from a net production of 20 nM h^{-1} to a net uptake of 30 nM h^{-1} except for stations at or near the St. Joseph River mouth that showed uptake rates of up to 100 nM h^{-1} .
- Comparison of net fluxes to total (obtained with the N-15 ammonium tracer) uptake or regeneration rates in June 1999 showed that the two approaches yielded similar uptake patterns among stations. Variation among stations was less for regeneration rates than for uptake rates.
- Light conditions and phosphorus additions had minimal effects on the net fluxes of ammonium and amino acids at most stations, but both light and added phosphorus significantly enhanced ammonium uptake rates in St.

Joseph River mouth stations. These results imply that heterotrophic processes dominated at most stations except for those in the region of the St. Joseph River mouth where rates were high and influenced by autotrophic processes.

Conclusions:

1. Nutrient cycling rates (uptake and regeneration) were significantly faster at stations at the St. Joseph River mouth than at other stations in southern Lake Michigan during winter-spring of 1999 and 2000.
2. Observations on nitrogen dynamics suggest that heterotrophic activity dominated nutrient turnover and that rates were not phosphorus limited at stations outside of the St. Joseph River influence.
3. In contrast, autotrophic activity dominated nutrient dynamics at the St. Joseph River mouth as reflected by nitrogen flux increases in response to light and/or added phosphorus.

Collaborators:

Chen (modeling), Johengen (nutrient fluxes), Cotner (bacterial dynamics), Fahnenstiel (phytoplankton), Eadie (sediment resuspension),

1. Project Title: **The impact of a recurrent coastal plume on phosphorus dynamics and production in Lake Michigan**
2. Participants: Cotner, Biddanda, Johengen
3. Our hypotheses and current perspectives:

Hypothesis 1- The recurrent coastal plume and/or resuspension of bottom sediments generates an increased inventory of total P and bioavailable P in the water column. This increased inventory is important to the development of the spring phytoplankton bloom.

- ◆ P in the water column increases, mostly as particulate P
- ◆ P-turnover times and alkaline phosphatase assays suggest that the particles may actually be sorbing P from the water, making it less available to plankton
- ◆ Rivers are an important source of dissolved P and organic matter to nearshore plankton
- ◆ Rivers also an important source of photo-labile dissolved organic matter.

Hypothesis 2-Heterotrophic bacteria function as “scavengers” of P in the coastal plume and maintain P availability in the water column.

- ◆ Bacterial biomass increased substantially during the 1998 resuspension event
- ◆ Carbon and other nutrients that are loaded into the water column from the sediments and rivers stimulate bacterial production at this time
- ◆ Bacteria are an important sink for P

Hypothesis 3- The inventory of TP and available P within the plume decreases as the plume ages, as a result of biotic incorporation and settling.

- ◆ Regions with elevated total P levels during a resuspension event, exhibit significantly lower P levels on follow-up cruises.
- ◆ Post-plume total P levels are lower than winter, pre-plume levels, and regions within the plume show a greater decline than non-plume affected regions.

Hypothesis 4- The bioavailability of P on the particles is governed by (a) equilibrium with solid Ca-PO₄ phases; (b) dissolution kinetics of CaPO₄ phases; and/or (c) adsorption/desorption kinetics of PO₄ on the Fe and Al oxides of the particles.

We have not addressed this hypothesis because our budget was cut.

Hypothesis 5- Water column P regeneration is more efficient during development of the recurrent coastal plume, minimizing losses to the sediments at this time.

- ◆ Bacteria take up a large fraction of available P during resuspension events
- ◆ They do not sink and may stimulate planktonic production by retaining P in the water column through the unstratified and stratified seasons.
- ◆ This idea will be examined further by examining interannual variability in resuspension intensity, bacterial biomass and spring productivity.

THE MICROBIAL FOOD WEB COMPOSITION AND DYNAMICS DURING THE WINTER-SPRING TRANSITION IN SOUTHERN LAKE MICHIGAN.

Peter Lavrentyev, Paul Kovalcik, Deborah Hersha (The University of Akron), and Wayne S. Gardner (University of Texas). In collaboration with: Henry Vanderploeg and Joann Cavaletto (NOAA-GLERL), Marie Bundy (Academy of Natural Sciences)

Objectives:

(1) Determine the composition, abundance, spatial distribution, and growth rates of microzooplankton and nanoplankton. (2) Examine their trophic relationships with bacteria, phytoplankton, and planktonic copepods.

Approach:

(1) Microzooplankton and nanoplankton samples were collected from the standard EEGLE stations in southern Lake Michigan from February 1998 through April 2000 and examined using a digital microphotography system and cytological techniques.

(2) A series of the Landry-Hasset type dilution experiments were conducted at selected stations June 1999 and February-April 2000 to examine the grazing impact of planktonic protists on bacteria and phytoplankton. Some of these incubations were conducted in conjunction with the fluorescently labeled bacteria (FLB) experiments.

(3) The trophic interactions between planktonic calanoid copepods (*Diaptomus sicilis* and *Limnocalanus macrurus*) and microzooplankton were examined in a series of 24-h shipboard bottle experiments.

Results:

The microzooplankton biomass (1998-1999 data) in offshore waters was due primarily to mixotrophic oligotrichs and the dinoflagellate *Gymnodinium helveticum*. Following storm resuspension events, the nanoplanktonic suspension-feeding choreotrichs *Rimostrombidium* spp. became abundant, whereas tintinnids and colonial chrysophytes dominated the river-influenced waters. The highest and lowest concentrations of microzooplankton were found in the turbidity zones near the St. Joseph River and Chicago (Fig. 1)

The growth rates of specific protist taxa exceeded 1.0 day^{-1} and the microzooplankton community growth rates varied between 0.1 and 0.5 day^{-1} , increasing from February through April in 1999. The community herbivory and bacterivory rates (0 to 0.35 day^{-1}) were close to or even exceeded the growth rates of phytoplankton and bacteria.

The copepods *L. macrurus* and *D. sicilis* consumed maxima of 630 and $118 \text{ ng C of microzooplankton animal}^{-1} \text{ day}^{-1}$, respectively. These rates were similar to or higher than their herbivory rates (Fig. 2). Both copepods demonstrated selective predation on certain microzooplankton taxa.

Conclusions:

- (1) The abundance microzooplankton during the winter-spring transition period is comparable to the summer stratification period;
- (2) The offshore microzooplankton community has a uniform distribution, while there is a significant spatial heterogeneity in resuspension-influenced waters;
- (3) The predominant microzooplankton taxa possess high growth rates despite low water temperature and form important trophic links between phyto- and bacterioplankton and planktonic copepods.

IMPACT OF EPISODIC TRANSPORT AND RESUSPENSION ON COASTAL PHYTOPLANKTON PROCESSES: A CASE STUDY OF THE LAKE MICHIGAN RECURRENT COASTAL PLUME (RCP)

G. L. Fahnenstiel, S. E. Lohrenz, D. F. Millie, and O. M. E. Schofield.

The purpose of this project was to 1) characterize optical properties in the region of the RCP, 2) determine the effects of the RCP on important phytoplankton rate process, (e.g. photosynthesis, growth, etc.), and 3) determine the meroplanktonic potential of RCP species, with particular reference to the spring diatom bloom.

At this point in the project, all field experiments have been completed, and analysis and synthesis of results have begun. Much of the bulk and community level analyses are near completion, and several manuscripts are in preparation (a few even completed!). Taxon-specific information is still being counted, and likely will not be completed for another year. A brief summary of results is provided.

A large gradient in water-column light attenuation (KPAR) and concentrations of suspended particulate matter (SPM) was noted in southern Lake Michigan during the field program. Scattering was the dominant factor contributing to variability in light attenuation in the study area, especially at low wavelengths. Variability in particulate absorption was the primary source of variation in total absorption. Neither KPAR values nor SPM concentrations corresponded with chlorophyll (Chl) a concentrations, indicating no differences in phytoplankton biomass between plume- and non-impacted waters. Moreover, phytoplankton growth rates were also not correlated with SPM or KPAR, nor were significant differences noted between plume and non-plume stations. Sub-optimal maximum photosynthetic quantum yields were also indicative of constraints on phytoplankton growth throughout the study area.

Phytoplankton did not exhibit dramatic differences in the spectral shape of pigment absorption across plume gradients, and this was consistent with single cell determinations of absorption spectra. Differences in photoacclimation were apparently not occurring at a rate sufficient to produce clear spatial gradients in community pigment absorption. Diatoms and cryptophytes dominated the assemblages, often comprising greater than 85% of the Chl biomass. The positive associations of SPM concentrations and KPAR values with the relative contribution of diatoms to Chl a and KPAR values with the absolute contribution of diatoms to Chl a, along with the inverse relationship between the relative contributions of diatoms and cryptophytes to Chl a, corresponded with the spatial

Effects of resuspension events on restructuring phytoplankton communities

Linda M. Goad and Matthew L. Julius, CGLAS-U of M

Objectives

1. Identify the species composition of plume event phytoplankton floras.
2. Note floristic differences between spring and fall plume floras as well as assemblage composition outside of the plume.
3. Isolate abiotic and biotic variables effecting species composition in plume floras.

Approach

- Sampling was performed before and after plume events in the spring, summer and fall along transects in southern Lake Michigan. (baseline)
- In plume and out of plume phytoplankton sampling was performed along southern Lake Michigan transects during plume events. (effect)
- A series of short sediment cores were taken at the southern Lake Michigan stations. This sediment material was resuspended in the laboratory under varying light, temperature, and nutrient conditions to simulate plume conditions. (cause)

Results

Pre-plume spring phytoplankton floras can be generalized as follows:

- Phytoplankton numbers are relatively high, but species diversity is relatively low.
- Diatoms dominate species composition.
- Diatom species generally include delicate chain forming taxa, *i.e.* *Cyclotella michiganiana*, *Cyclotella ocellata*, *Fragilaria capucina*, and *Tabellaria fenestrata*

Plume event phytoplankton floras can be generalized as follows:

- Phytoplankton numbers are relatively low, but species diversity is relatively high (caused by the number of benthic and other taxa reintroduced to the water column).
- Diatoms dominate species composition.
- Taxa are most frequently resting cell forming species, which are rapidly expanding and dividing. *Aulacoseira islandica* and *A. italica* are the most common, with *Fragilaria crotonensis*, *Stephanodiscus minutulus*, *S. subtransylvanicus*, and *S. alpinus* being the subdominant.

The pre-plume flora generally replaces the plume flora within 2 weeks of the plume events conclusion.

Sediment resuspension experiments in the laboratory indicate time may be the single most important factor. *Aulacoseira islandica* and *A. italica* always dominate the species composition in the initial phase of the resuspension experiment, regardless of modifications in light, temperature, and nutrients. Once the initial *Aulacoseira* spp. pulse has diminished, other species being increasingly abundant varying in relation predominately to differing light and temperature regimes.

Presentations at meetings

Julius, M.L. and Goad, L. Initial investigation of the relationship between periodic resuspension events and diatom blooms in Lake Michigan. Presented at the 15th North American Diatom Symposium, Pingree Park, CO, 1999.

Julius, M.L. and Goad, L. Relationship between periodic resuspension events and phytoplankton blooms in Lake Michigan. Presented at the 54th Phycological Society of America Meeting, San Diego, CA, 2000.

dominance of diatoms and cryptophytes in near- and offshore waters. The large, chain-forming centric diatoms that typically dominate Lake Michigan assemblages during the spring diatom bloom were not abundant within plume-impacted waters; rather, small centric diatoms were abundant.

The occurrence of fucoxanthin and Chl a, along with the abundance of small centric diatoms within the surficial sediment layer, established the presence of diatoms and confirmed this layer as a potential source of meroplankton. A large scale experiment conducted in the spring of 2000, verified the importance of meroplanktonic diatoms, and the limited role of plume materials in stimulating phytoplankton growth. Although resuspension of benthic diatoms appears to be important to the development of phytoplankton assemblages within nearshore, plume-impacted waters, it has little, if any relationship with the development of the annual, spring diatom bloom.

SCIENTIFIC JOURNAL ARTICLES TO DATE : Lohrenz, S. E., G. L. Fahnenstiel, G. J. Kirkpatrick, C. L. Carroll, and K. A. Kelly. 1999. Microphotometric assessment of spectral absorption and its potential application for characterization of harmful algal blooms. *J. Phycol.* 35:1438-1446.

Fahnenstiel, G. L., S. E. Lohrenz, K. Kelly, D. F. Millie, and O. M. E. Schofield. 2000. Light absorption characteristics of individual phytoplankton cells from a natural community: Examples from Lake Michigan during the winter period. *Verh. Internat. Verein. Limnol.* 27: IN PRESS.

Fahnenstiel, G. L., R. A. Stone, M. J. McCormick, C. L. Schelske, and S. E. Lohrenz. Spring isothermal mixing in the Great Lakes: Evidence of nutrient limitation and nutrient-light interactions in a sub-optimal light environment. *Can. J. Fish. Aquat. Res.* IN PRESS.

Millie, D. F., G. L. Fahnenstiel, S. E. Lohrenz, H. J. Carrick, and O. Schofield. Effect of a recurrent sediment plume on phytoplankton biomass and group dynamics in southern Lake Michigan. Submitted *Can. J. Fish. Aquat. Sci.*

These manuscripts will be made available at the Homestead Meeting

Daphnia resting egg production and resuspension: records from sequential sediment traps

W. Charles Kerfoot¹, Xiao Ma¹, Brian J. Eadie², and J. Budd¹

¹MTU and ²NOAA-GLERL

Objectives: How biodiversity is maintained in lakes involves processes that operate over radically different time scales. Population growth of resident species is an aspect traditionally emphasized in planktonic studies. That is, population studies document how the balance of births and deaths play out seasonally to alter species appearance, density and community composition. Fluctuations from year to year are compared with various climatic or biotic variables (temperature, resources, predators). A much longer time-scale process involves the formation of a viable “seed bank” of resting eggs and periodic resuspension and hatching of those eggs. This process is intimately tied to both the biological seasonal cycle as well as to longer-term processes such as sedimentation, water column stratification, bioturbation of benthic sediments, yearly sediment resuspension, and the frequency of major perturbations that disturb sediments (i.e. storm-driven sediment plumes). Many resting eggs remain near the site of production, lying on the surface of sediments to hatching the following spring. Some are thought to float, to be blown over in wind rows, plastering along shorelines, to be resuspended the subsequent spring during the spring high water period. However, certain resting eggs are buried in sediments, entombed away from hatching cues, and survive for decades (Kerfoot et al. 1999). Resting stages of organisms previously buried several centimeters deep in pelagic to nearshore sediments may be periodically resuspended and redistributed by major storms which produce major fall-spring sediment plumes. At the population level, the deep resuspension process could be important for maintaining genetic diversity. These wind-driven episodic events could also alter seasonal plankton biomass or even change community composition, as resuspended zooplankton resting eggs may re-establish rotifer, cladoceran (*Daphnia*, *Bythotrephes*, *Bosmina*), and copepod (*Diaptomus minutus*) populations lost over short intervals. Our efforts cross-connect with the sediment resuspension and zooplankton trophic dynamics group.

Approach: We have concentrated on resting eggs of two cladocerans, *Daphnia* and *Bythotrephes*, because 1) both species are easily retrieved from coarsely filtered sediment samples, 2) *Daphnia* species are native, whereas *Bythotrephes* is an exotic species introduced in the mid-80's, and 3) the two genera contrast current-dispersed with fish-dispersed types of resting eggs (Jarnagin 1998; Jarnagin et al. 2000). Previously, information on resting egg production and resuspension were unavailable, because October-March seasons are a dangerous time out on the Great Lakes.

Results: Deployed during the seasons of 1997-2000, sequential sediment traps captured large numbers of *Daphnia* ephippia, clearly distinguishing patterns of seasonal production from resuspension events. Seasonal production occurred within a relatively narrow time interval, about one and one-half months, from late October through early December (Fig. 1). Production (Fig. 2) of ephippia was highest in deepest waters (170-1079 ephippia per trap) and declined linearly with depth towards the shorelines (10-30 ephippia per trap). Resuspension is characterized by out-of-season resting egg deposition highly correlated with mass sedimentation. Incidental capture occurred sporadically in winter and

early spring at shallow-water sites, coinciding with periods of major sediment resuspension events (plumes). Out-of-season resuspension averaged 14.0 \pm 7.1(95% C.L.) ephippia/trap or less than 1% of total yearly production at central sites and over 100% of yearly production at shallow-water sites, underscoring the importance of resuspension along the shallow-water margins of southern Lake Michigan in late winter and early spring. Resuspension of resting eggs did not occur during late spring and summer, especially during periods of water column stratification.

Preliminary analysis of sediment cores showed that resting egg “seed banks” were found in high sediment deposition regions, not necessarily at the deepest sites, where production was maximum. Ephippia at central, deep-water sites showed signs of predation (bite marks, half-opened cases). Rapid burial and removal from the bioturbation zone seems important to the formation of resting egg “seed banks”. A preliminary resting egg production/burial model suggests that a delicate balance between burial and predation is crucial to successful accumulation of resting eggs in the “seed bank”. We suspect that *Diporia* and planarians may be important consumers within the bioturbation zone. Sediment cores suggest that “seed bank” reservoirs (latent recruitment grounds) are restricted in spatial extent, yet entomb sizable numbers of long-term surviving individuals. Electrophoretic studies of these seed banks documents a surprisingly rapid evolution of *Daphnia* populations, showing significant gene frequency changes in 20-30 years in harbor (estuary) populations, and 60-80 years in deep-water populations. We are exploring the possibility of utilizing 210-Pb and 137-Cs profile anomalies to document the frequency of past large storms.

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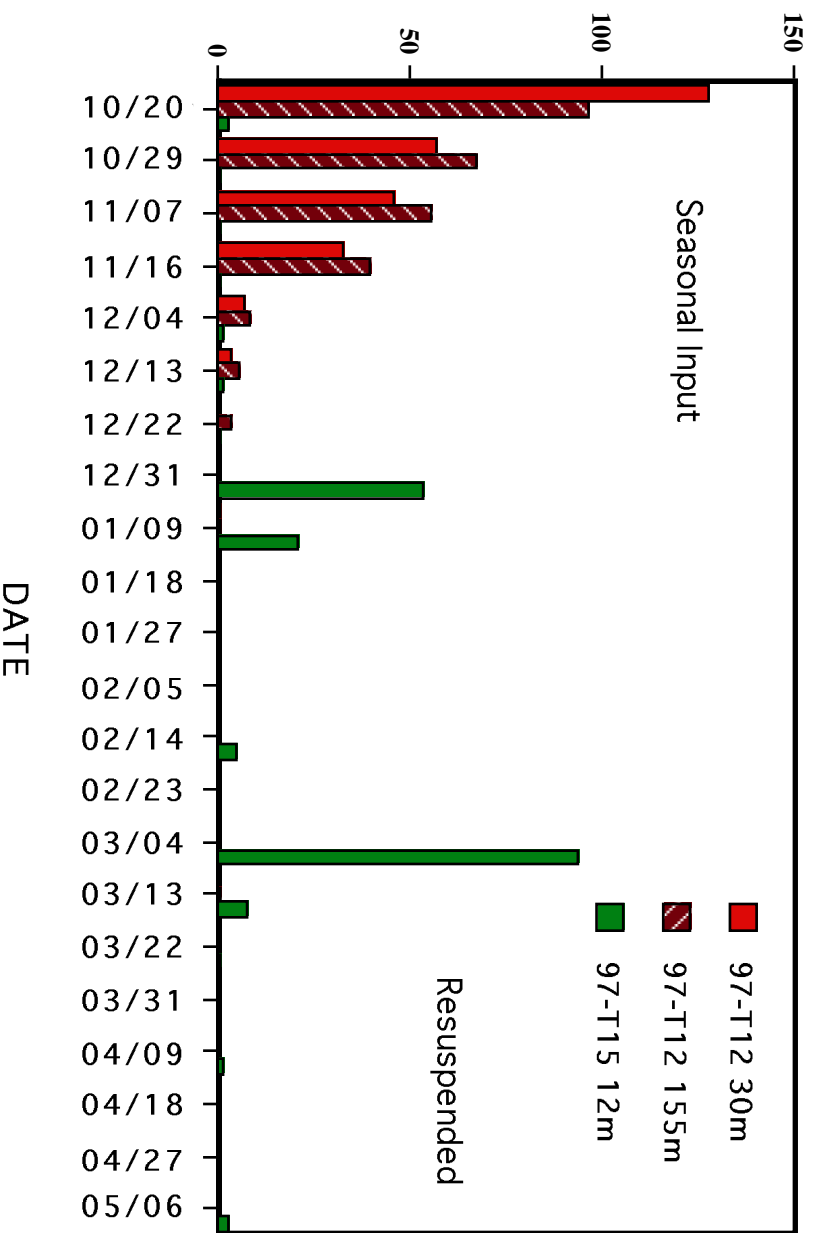
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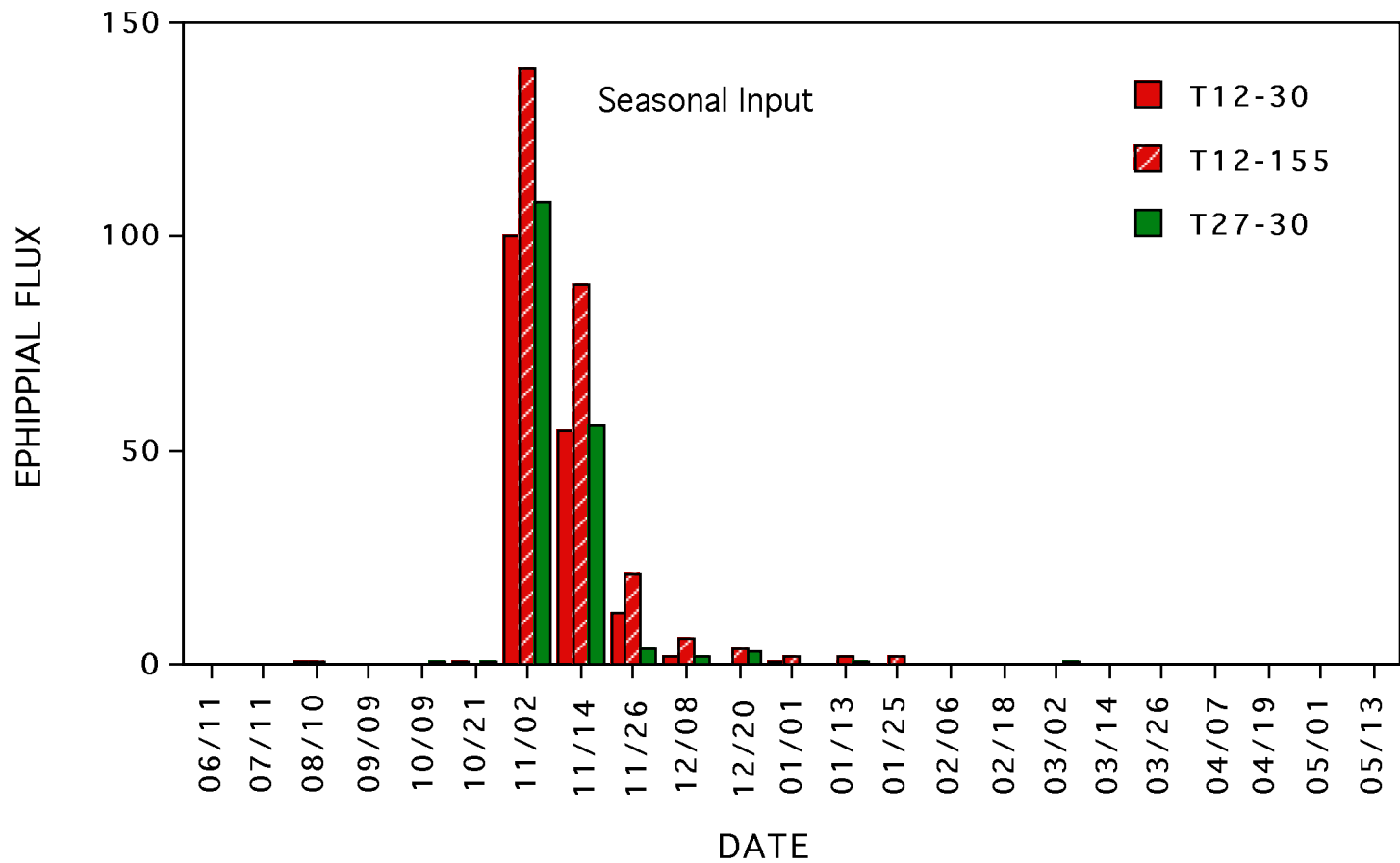
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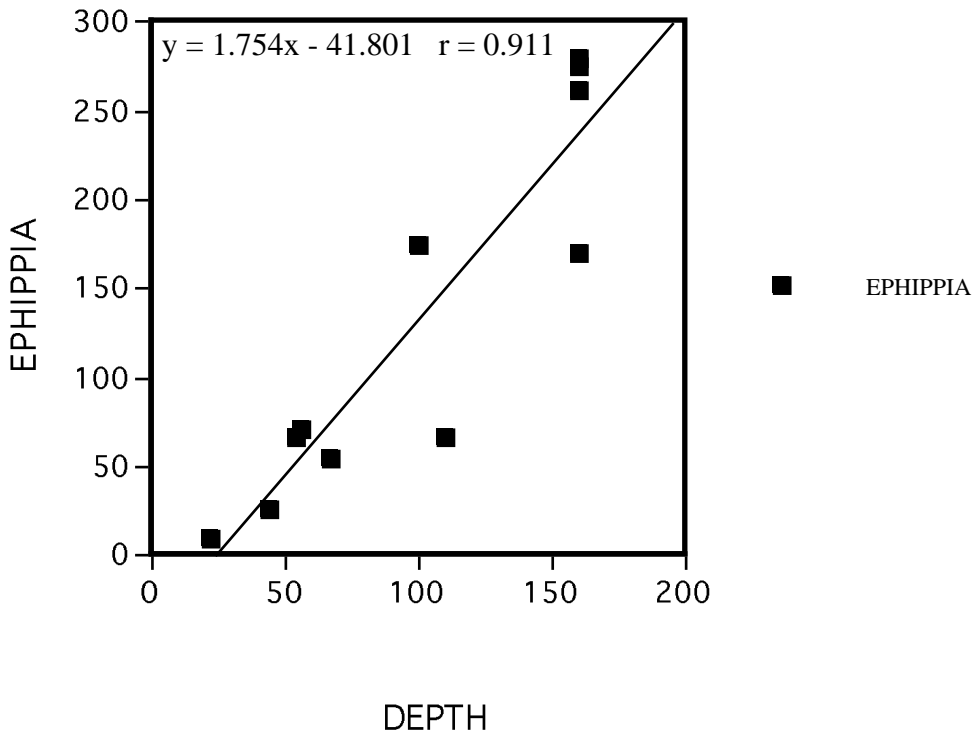
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LAKE MICHIGAN



The Recurrent Coastal Plume in Lake Michigan: A Critical Event for Copepod Reproduction and Recruitment

H. Vanderploeg and M. Bundy

Preliminary results of grazing experiments conducted in 1998, 1999, and 2000 reveal that the dominant calanoid copepods (*Limnocalanus macrurus* and *Diaptomus sicilis*) exhibit size selective feeding, with lower grazing rates on $< 10\ \mu\text{m}$ phytoplankton and elevated grazing rates on larger cells. In particular, *D. sicilis* preyed heavily on the $10\text{--}53\ \mu\text{m}$ and $> 53\ \mu\text{m}$ component of the phytoplankton community, while *L. macrurus* preyed heavily on the $10\text{--}53\ \mu\text{m}$ component, but did not graze on the $> 53\ \mu\text{m}$ size fraction.

When these data are coupled with those of Lavrentyev and Kovalcik, it appears that production of zooplankton should be elevated when a more heterotrophic food web dominates, compared to when phytoplankton dominate. Both calanoids had elevated grazing rates on protozoan prey, with clearance rates of microzooplankton reaching 10 times that of phytoplankton. If in fact the plume's sediment load promotes a more heterotrophic food web, then overwintering copepods may get a significant boost from increased concentrations of microzooplankton. This is important because the late winter/early spring is a critical time for reproduction of these animals. Grazing studies with nauplii suggest that new copepod production will probably also be elevated when there is increased productivity of the microbial food web, although we have not comprehensively looked at feeding of juveniles.

Scheduled monthly "monitoring" cruises starting in September 1998 on Muskegon and St. Joseph transects were carried out to characterize the plankton community. Discrete samples of nutrients, size-fractionated chlorophyll, and suspended solids were sampled at 15-m, 45-m, and offshore sampling sites on each transect (Fig. 1). We also did a major cruise in June that covered all transects (Racine, Chicago, Gary, St. Joseph, and Muskegon) to evaluate offshore-onshore patterns at a variety of sites in the southern basin (Fig. 1) outside of the plume time frame. There were tremendous differences in the nearshore areas among some of the transects. For example, chlorophyll concentration was lower and zooplankton concentration was very much lower in the nearshore area near Chicago as compared to Muskegon (Figs. 2a, 2b, 2c, 2d). These data are the first to fully span the inshore to offshore and show that inshore regions of different parts of the southern basin are very different. Note we did also sample at the deepest portion of the southern basin, the station labeled DWS in Fig. 1. Major differences were also seen in nutrients in the different regions. For example, diatom production (as measured by the accumulation of biogenic silica) in the St. Joseph region was significantly depressed relative to that near Muskegon for 3 months during 1999.

The PSS showed that zooplankton counts were similar in March 1998 and March 1999 transects; however, PSS-measured biomass was considerably lower in 1999. This correlated to a shift from *Diaptomus* spp. to cyclopoids, which are smaller and more predacious than *Diaptomus*, and a shift from large to small species of *Diaptomus*. This was probably due to a strong year class of alewives preying on larger zooplankton. Over 100 zooplankton samples have been counted from the St. Joseph transects and we are beginning to determine their biomass from length weight regressions so we can calibrate biomass seen with the PSS. Likewise fluorescence will be correlated to chlorophyll measurements. The fish predation driven changes outweigh any impact of plume-driven changes. The shift in zooplankton composition to cyclopoids and small diaptomids implies a shift away from predation on large diatoms to microzooplankton. Examination of data from 2000 revealed a return to the usual community dominated by medium and large-sized diaptomids.

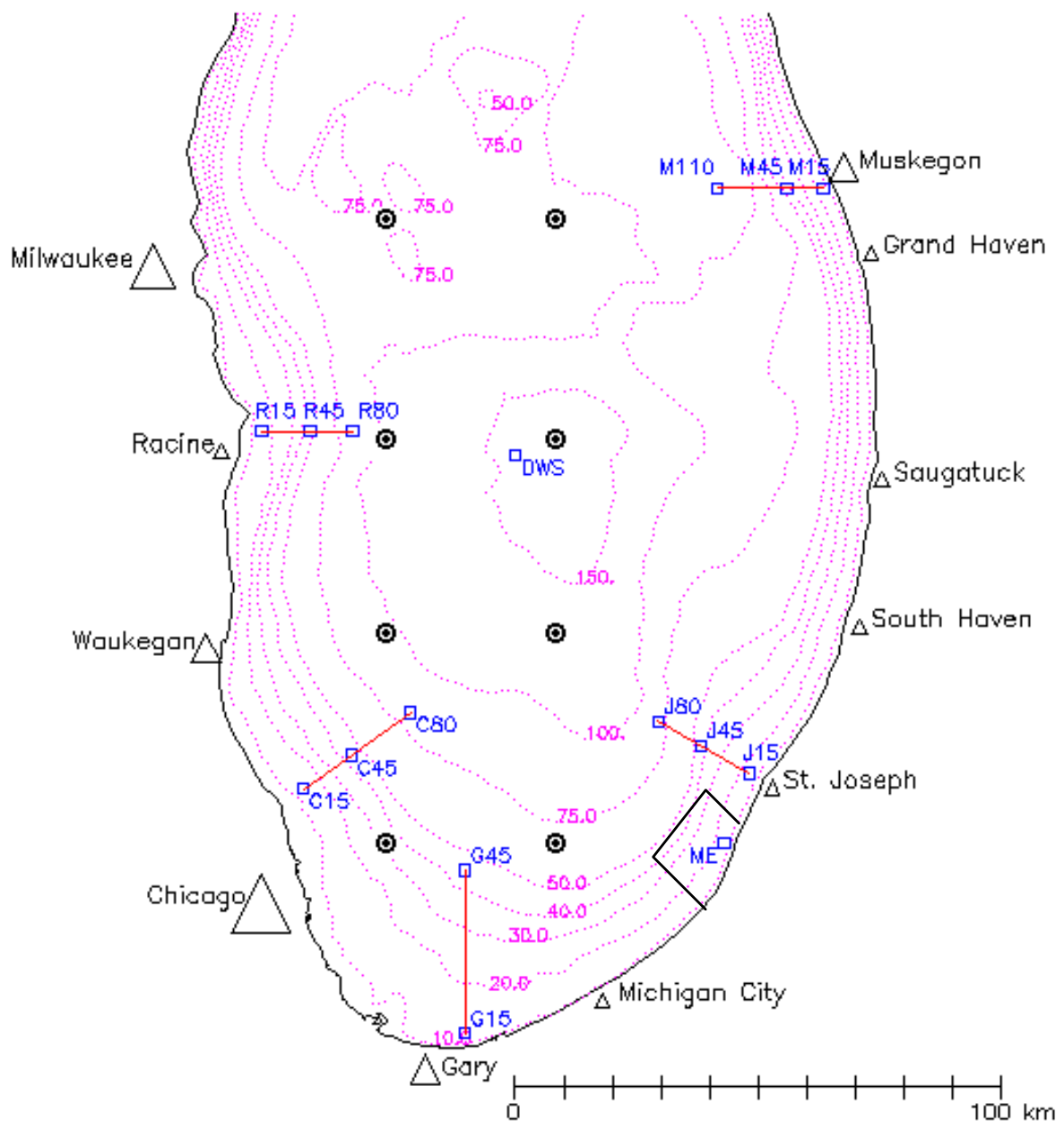


Figure 1. Location of EEGLE sampling stations and transects in southern Lake Michigan.

Survey area for Evans *et al.* (1980) study represented by box surrounding symbol ME.
Stations for Makarewicz *et al.* (1995) study represented by circles.

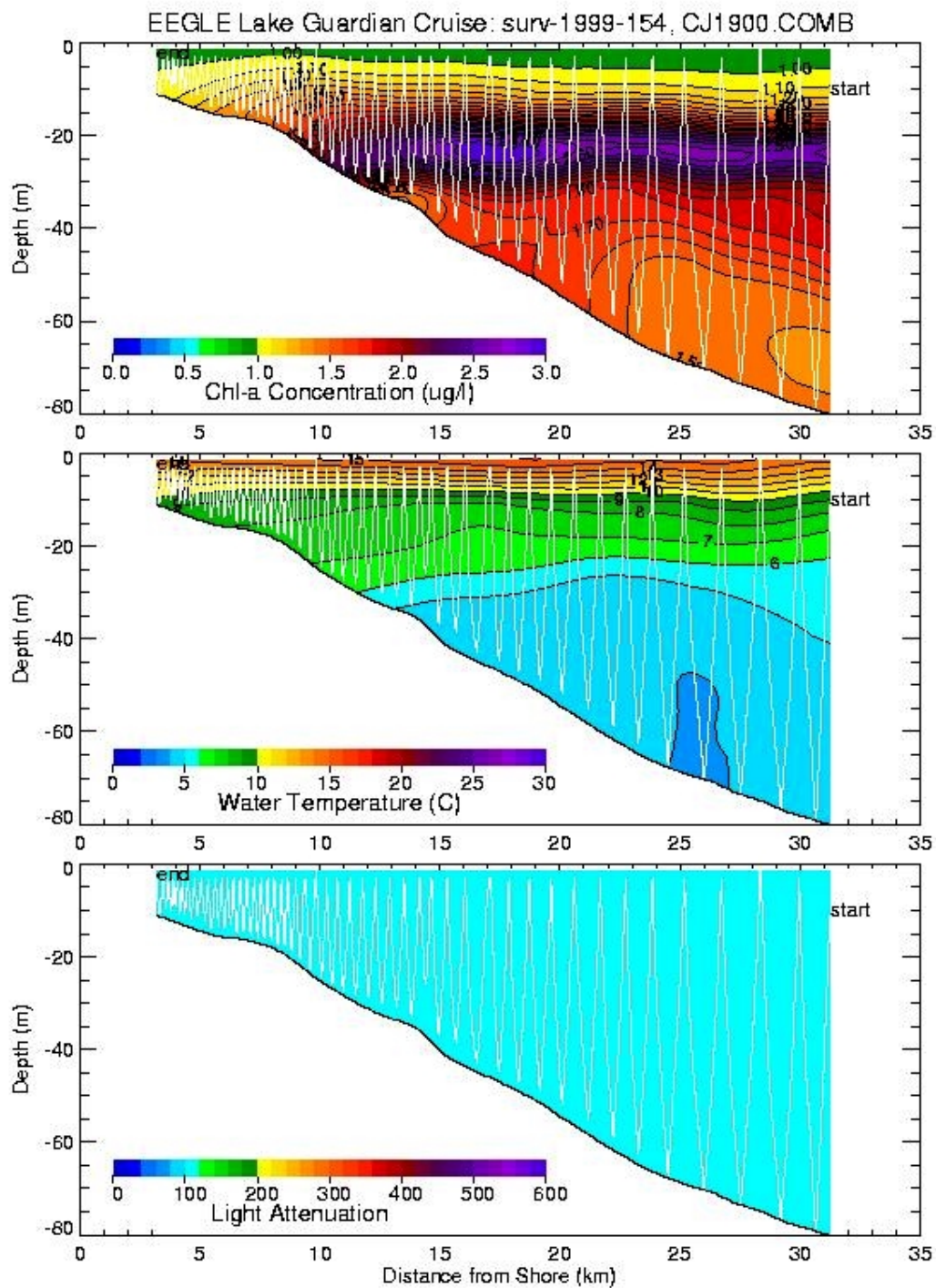


Figure 2a. Chicago transect in early June 1999: Chlorophyll fluorescence, water temperature, and light attenuation. White sinusoidal lines on panels are PSS traces.

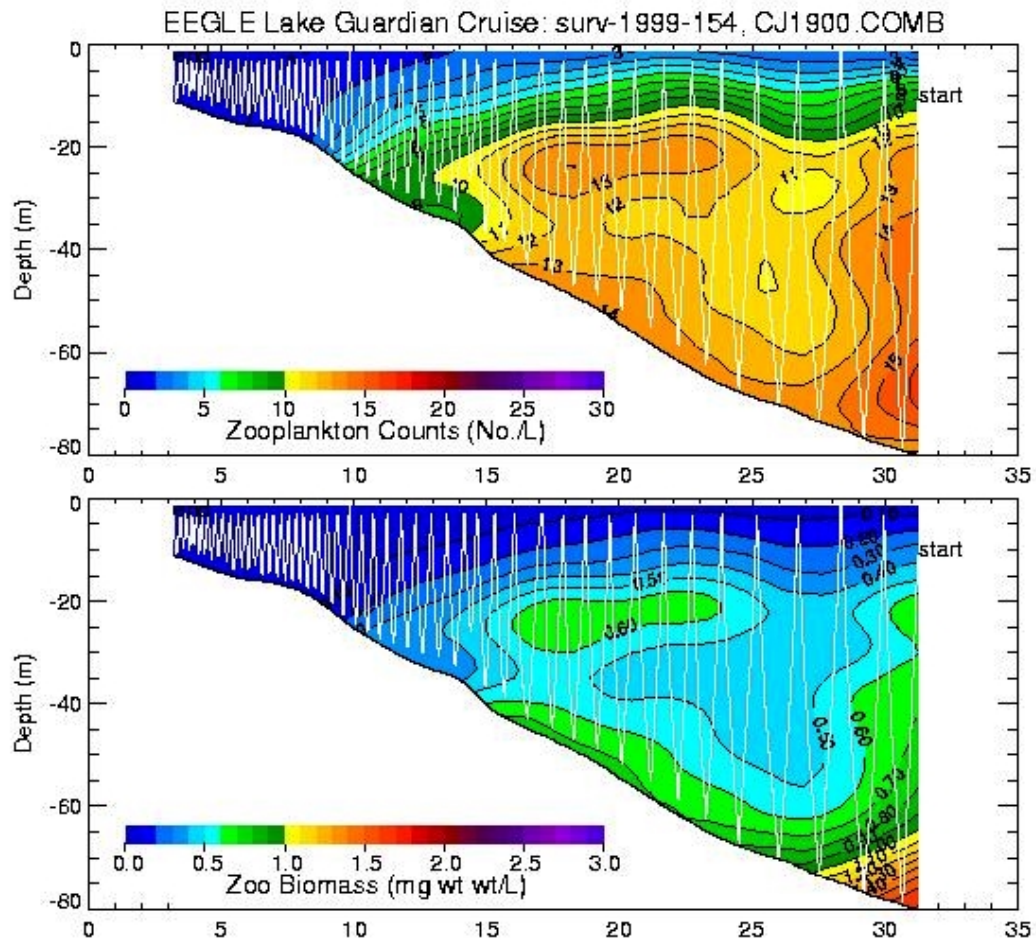


Figure 2b. Chicago transect in early June 1999: Zooplankton number concentration and biomass.

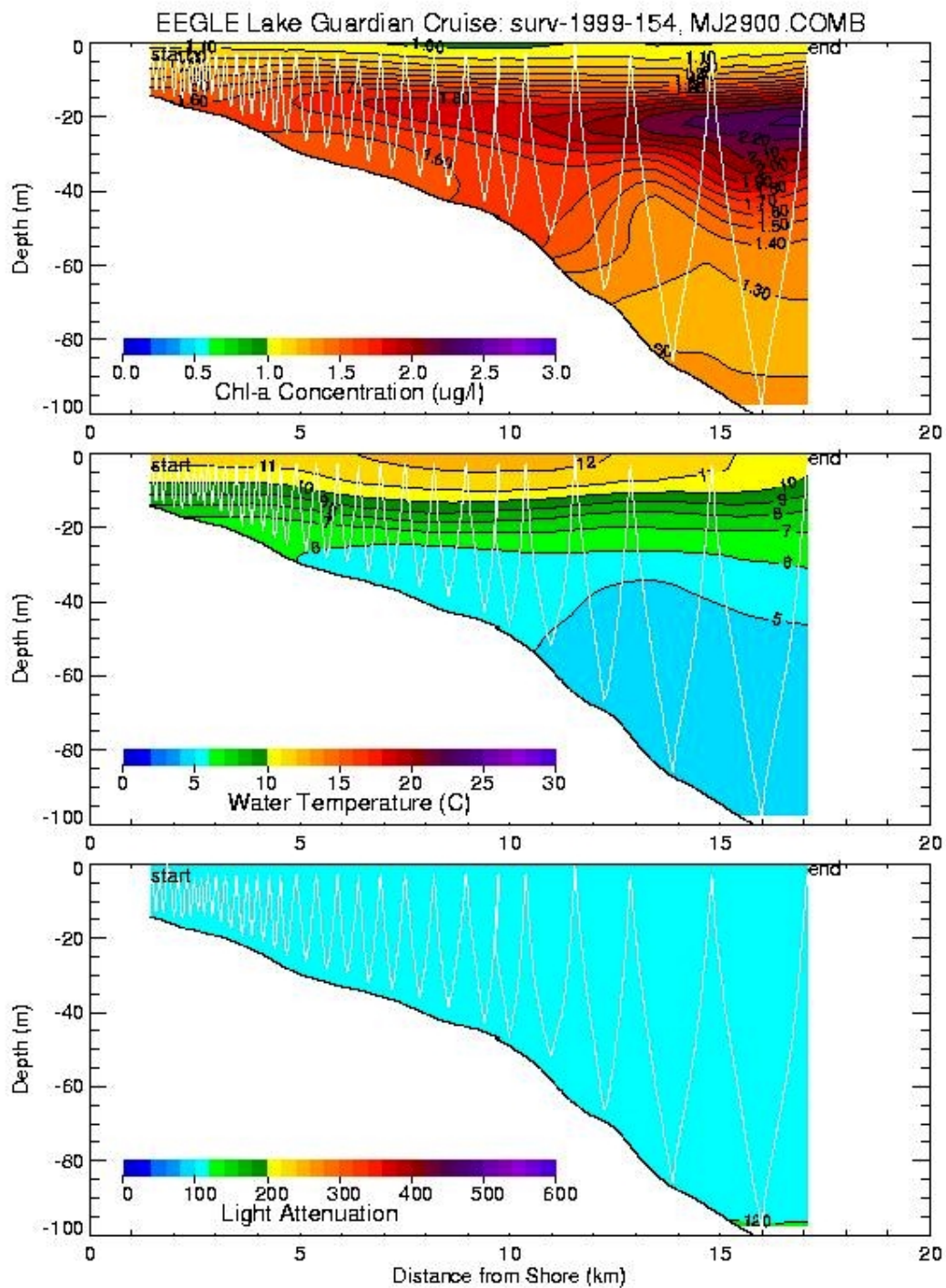


Figure 2c. Muskegon transect in early June 1999: Nominal chlorophyll concentration, water temperature, and light attenuation.

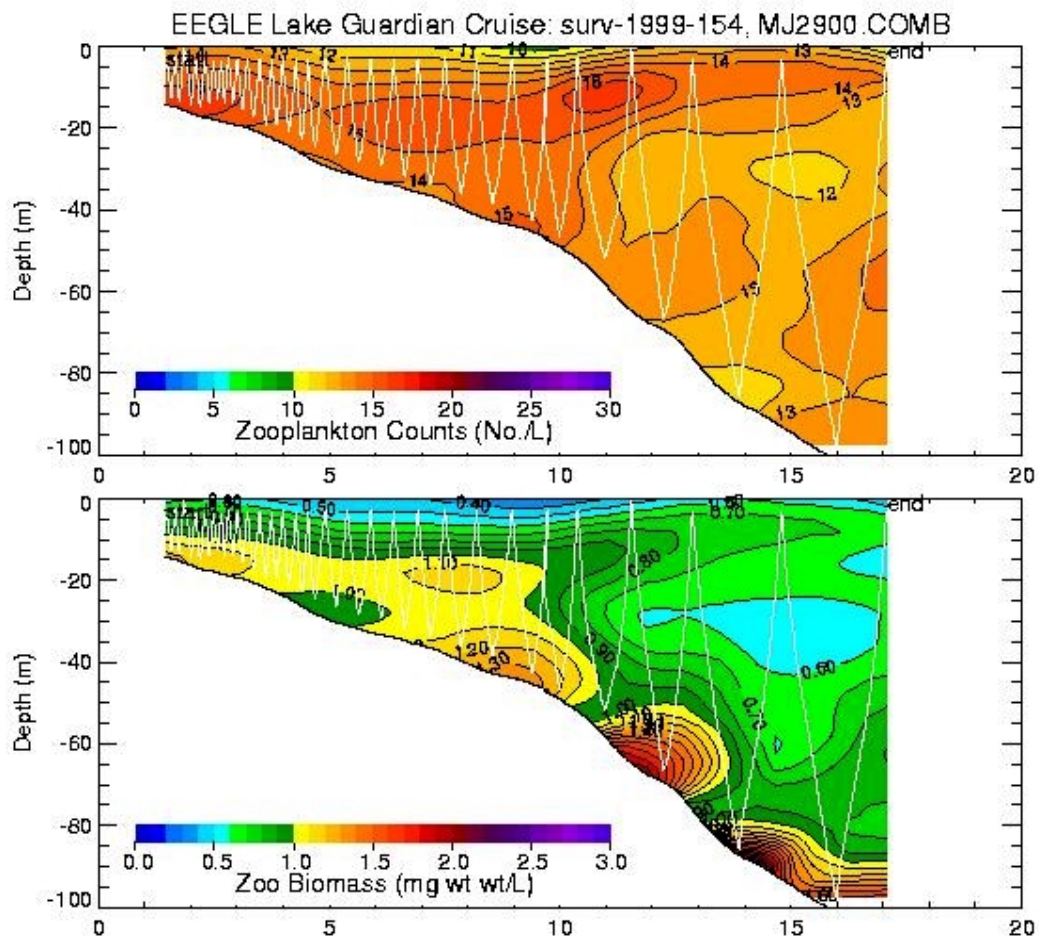


Figure 2d. Muskegon transect in early June: Zooplankton number concentration and biomass.

Modeling Studies of the Plume Ecosystem in Lake Michigan

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The plume ecosystem of Lake Michigan was examined using a 3-D coupled physical and biological model. The physical model is the Princeton Ocean Model (POM) and the biological model is a phosphorus-controlling lower trophic level food web model including 7 state variables (phosphorus, small and large phytoplankton, small and large zooplankton, bacteria, and detritus). The coupled model was forced by the 1998 and 1999 real-time wind and net heat flux under wintertime climatological initial conditions and ran prognostically with input of the real-time suspended sediment concentration derived directly from temporally and spatially interpolated satellite imagery (with correction using data samples).

The model results show that the spatial distribution of the biological field was closely related to the physical environment associated with 3D circulation and mixing. The different spatial patterns of the chlorophyll-a concentration found in southern Lake Michigan in 1998 and 1999 were well coherent with the spatial distribution of the model-predicted 3D circulation for these two years.

The suspended sediments in the reflective, recurrent coastal plume had a significant impact on the spatial distribution and temporal variation of the nutrients and plankton in southern Lake Michigan in 1998 and 1999 spring seasons. The nutrients released from suspended sediments were critical to maintain the nutrient level in southern Lake Michigan. The growth of phytoplankton in the plume depended on the availability of nutrients and light, but the cross-shelf decrease tendency of phytoplankton was controlled by a ratio of the euphotic depth to the mixed layer depth. The photosynthesis inhibition due to both light intensity and suspended sediments led to a subsurface maximum of primary production, but had little influences on the spatial distribution of phytoplankton biomass as a result of strong vertical mixing.

The cross-plume fluxes of nutrients and phytoplankton were mainly driven by episodic wind events with a period of about 5 to 7 days: offshore during northerly winds and onshore during southerly winds. The flux estimates among biological variables in the food web system suggested that the microbial food web played an important role in the secondary production in southern Lake Michigan. The lower trophic level food web system could be divided into two decoupled loops: (1) detritus-bacteria-microzooplankton-large zooplankton and (2) nutrient-phytoplankton-detritus.

The model-predicted spatial distributions of nutrients and phytoplankton were in reasonable agreement with observations taken during the 1988 and 1999 EEGLE interdisciplinary cruises, suggesting that the model was robust to capture the basic characteristics of the plume ecosystem in southern Lake Michigan.